Man's Place in Space-Plane Flight Operations

Cockpit, Cargo Bay, or Control Room?

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The military potential of manned spacecraft may remain an unresolved question for a long time.

—Maxime Faget

THESE WORDS, written by one of the National Aeronautics and Space Agency's (NASA) founding fathers and a driving force behind America's first manned space program (Project Mercury), were prophetic considering the United States Air Force's renewed interest in "space-plane" technology during the last decade of the twentieth century. Consider, for example, the *Spacecast 2020* study published in 1994,[1] which envisioned "a squadron of rocket-powered transatmospheric vehicles . . . capable of placing an approximately 5,000-pound payload in any low earth orbit or delivering a slightly larger payload on a suborbital trajectory to any point in the world."[2] This was followed in 1995 by the *New World Vistas* study,[3] which recommended "establish[ing] the technical feasibility of an unrefueled global-range aerospace plane to perform reconnaissance and strike functions anywhere on the globe."[4] Finally, in June 1996 the *Air Force 2025* study[5] accomplished by Air University included a "single stage space plane"[6] among the top 10 systems that would best ensure continued US dominance of air and space into the next century. Although each of these studies used different

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terminology—transatmospheric vehicle, aerospace plane, and multipurpose transatmospheric vehicle—they all clearly referred to the same basic capability. This article uses the nomenclature *military space plane* (MSP) for the reusable, hypersonic, aerospace vehicle envisioned by these long-range studies.

Research Objectives

The Air Force has not yet engaged in a rigorous discussion of whether an MSP should be configured to carry a crew. When broached, the question is usually posed in oversimplified terms: "Should an MSP be manned or unmanned?" The overall goal of this article is to open the discussion of this complex issue by putting it in a more proper perspective. The three specific objectives are to

1. Demonstrate the lack of consensus in the manned versus unmanned space-plane debate by summarizing the existing literature and contrasting the supporting evidence from each viewpoint.
2. Approach the problem from a different perspective by considering an entire spectrum of man-machine interface (MMI) possibilities for MSP operations. Viewed in this context, the presence or absence of a man on board is the output of a structured design analysis and not an a priori design requirement.
3. Use this new approach to conduct a preliminary MMI analysis to answer the question posed by this article's title: Does man belong in the MSP cockpit, cargo bay, or control room?

To meet these objectives, the next section builds a foundation for MSP system requirements by reviewing current Air Force space operations doctrine. After that, the manned-versus-unmanned space-plane debate is summarized to include a sampling of existing space-plane concepts with widely varying thoughts on how man should (or should not) be used in their operation. The article's focus then shifts away from the manned-versus-unmanned paradigm towards an entire spectrum of man-machine interface possibilities. A structured process for selecting an MMI design is identified, and existing data on the performance of humans in space is presented to provide insight to the results of this process for an MSP. Finally, key findings and recommendations are summarized to include one depiction of how man may ultimately be integrated into an operational MSP system.

Military Space-Plane Mission Requirements

Before assessing the proper place for humans in an MSP, it is important to understand current USAF space operations doctrine. A general understanding of the four mission areas prescribed by this doctrine is necessary for the mission-to-task analysis presented later. A brief sketch of "draft" MSP system requirements is also provided.

Space Operations Doctrine

Space force operations, according to Air Force Doctrine Document (AFDD) 2-2, *Space Force Operations*, are categorized in four mission areas: Space Control, Application of Force, Enhancing Operations, and Supporting Space Forces.[7] Space Control, achieved via counterspace missions, is the means by which use of the space environment is assured to friendly forces and denied to enemy forces. Offensive counterspace missions deceive, disrupt, deny, degrade, or destroy enemy space forces by targeting the enemy's space, ground, or communications link nodes. Defensive counterspace missions protect our own space forces.[8] Application of Force is defined as "attacks against terrestrial-based targets carried out by military weapon systems operating in space."[9] Although we do not currently possess this capability, developments in technology and national policy may change this situation in the future. Enhancing Operations encompasses "those operations conducted from space with the objective of enabling or supporting terrestrial-based forces."[10] This mission area accounts for most of today's space operations to include navigation, communication, surveillance and reconnaissance, missile warning, and environmental sensing. Finally, Supporting Space Forces operations "deploy, sustain, or augment on-orbit spacecraft, direct missions, and support other government or civil organizations."[11] Common examples include both space lift and on-orbit satellite operations (e.g., telemetry, tracking, and control). Other Supporting Space Forces missions made possible by reusable launch vehicles include retrieving spacecraft so they can be refueled and repaired or even maintaining spacecraft on orbit to extend their useful life.

MSP Requirements

To support these four mission areas in the future threat environment, Air Force Space Command (AFSPC) has drafted Mission Need Statement (MNS) 001-97, "Tactical Military Operations in Space," which proposes "a new, reusable, launch-on-demand, multipurpose military space system designed for tactical space operations, called the Military Spaceplane."[12] Near-term (three to six years) MSP requirements focus on "defensive counter-space to protect existing assets" (Space Control), and "limited on demand Force Enhancement (surveillance and reconnaissance)."[13] Medium- to long-term (six to 18 years) requirements include space superiority; space surveillance and space object identification (Space Control); navigation support, intelligence, surveillance and reconnaissance, meteorology and theater/national missile defense (Enhancing Operations); and the deployment, repair, refueling, and servicing of satellites (Supporting Space Forces).[14] Draft MNS 001-97 also refers to the need "for rapid, global precision strike to augment conventional delivery systems" (Application of Force).[15]

The draft system requirements document for an MSP[16] specifies a variety of man-machine interface requirements for an MSP flight vehicle. Consider the following three specific requirements from this draft:

> The Military Spaceplane System should accommodate male and female crew members of no less than 100 pounds and no more than 240 pounds and a height of no less than 60 inches and no more than 76 inches.[17]
>
> The Spaceplane . . . shall be capable of autonomous execution of preprogrammed missions with or without a crew onboard.[18]
>
> The flight crew shall be able to direct the Spaceplane either from onboard the Spaceplane or from the ground or support vehicles via a virtual crew interface. This capability shall be provided with or without a crew onboard.[19]

The first two passages require an MSP to operate in both the "manned" and "unmanned" modes. The third, which refers to a "virtual crew interface," implies that other options exist—an observation that will be explored later. However, it is not yet clear whether these requirements are valid or even appropriate—issues that will also be addressed later. But before pursuing these ideas, the next section investigates the insidious manned-versus-unmanned space-plane debate present in the current literature.

The Current Debate: Manned versus Unmanned

The argument for putting a human operator on board a space plane is mostly qualitative. It centers on the fact that man's cognition, judgment, and experience provide an inherent flexibility to react to unanticipated events that cannot be matched by machines.[20] Although few human beings would take exception to this view, it is difficult to quantify its benefit. "There is no way that a price tag can be placed on such characteristics as flexibility or serendipity[21] because the essence of these attributes is the ability to capitalize on the unanticipated or unknown."[22] On the other hand, the argument against having a human operator on board is primarily quantitative. Proponents of unmanned systems quantify their support in terms of lower costs (since the system need not achieve a "man-rated" reliability), increased payload capability (since the crew and their life-support systems can be replaced with payload), and less risk to human life. Of course, neither of these arguments is iron clad. To illustrate this, a more detailed breakdown of each side's case will be presented according to specific parameters common to any engineering trade study—namely, cost, safety, technology, and program risk. A few other issues will be highlighted as well.

Cost. With the possible exception of a space plane's weight, whether or not it has a human operator on board is the overriding determinant of its cost.[23] For example, cost estimates of the Skylon space-plane concept suggest that man-rating the vehicle will increase development costs by 50 percent.[24] Existing data from commercial airliners suggest that 25 percent of development costs go towards cockpit design.[25] Unmanned space-plane advocates also suggest that the complexity of an integrated cockpit design can only inflate operating costs. Since "servicing activities become more complex to ensure that the crew compartment and vehicle are safe for the next mission,"[26] direct operating costs increase.

Proponents of manned space planes have a different set of cost figures. The Sanger space-plane designers estimate the per-flight cost of their manned configuration is only 10 percent higher than their unmanned configuration.[27] Since the MSP vehicle itself will have to "survive" each sortie, flight profiles and design considerations will keep G-load, thermal environments, and other stress factors within reasonable bounds. In other words, the basic MSP design philosophy will be inherently consistent with man-rating considerations.[28] Additionally, unmanned vehicles have hidden costs for autonomous or remote guidance and control systems that may exceed the cost of outfitting the vehicle for a crew.[29] Finally, the cost of installing and operating telemetry, tracking, and control (TT&C) sites erodes any cost advantage of unmanned systems even further.

Safety. From a space-plane flight crew's perspective, the risk to human life is certainly minimized by an unmanned vehicle configuration. But what can be said about the risk to the civilian population beneath the vehicle's flight path?

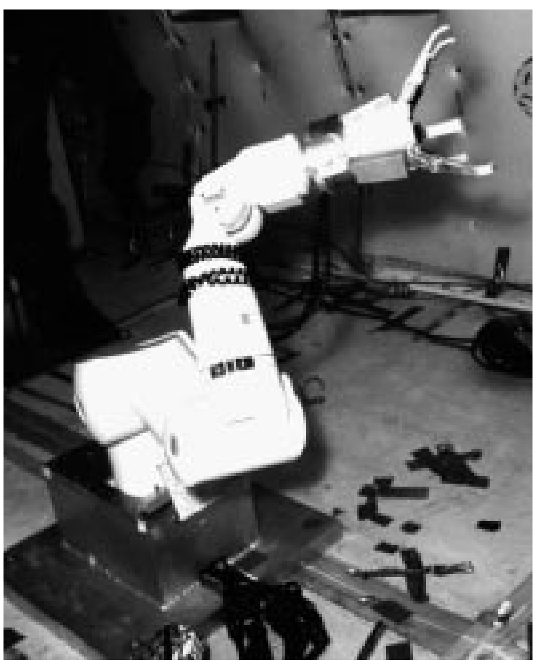
NASA photo

The first US "space walk." Astronaut Edward H. White II, attached by an umbilical and tether line to Gemini 4, floats in space. Extravehicular activities (EVA) were an essential buildup in NASA's manned space program.

Proponents for a manned system say this is where the flexibility of a human operator is vital. According to a study done on the X-30 (a national aerospace plane [NASP]technology demonstrator), a pragmatic MSP flight-test program will require a multitude of alternate landing sites throughout the continental United States (CONUS) to permit safe vehicle recovery if problems occur. "Because of numerous factors (weather, energy state, required test conditions, telemetry coverage, etc.), these recovery bases may not always be the same and, therefore, the (vehicle) must be designed to be capable of recovery into any base / lakebed with a long enough runway. Recovery from orbit will require similar landing flexibility."[30] Manned space-plane advocates suggest it would be cost prohibitive to outfit every alternate landing site with the specialized equipment necessary for either a remotely controlled or fully autonomous landing. Finally, current regulations prohibit flight of unmanned air vehicles outside restricted airspace without a "safety chase." Obviously, no aircraft exists that could chase an MSP.

Unmanned space-plane advocates counter these assertions. First, the technology exists to use Global Positioning System (GPS) signals for a precision approach to any runway with a minimum amount of specialized equipment.[31] (If GPS is jammed during hostilities, backup navigation aids could be planned for at a minimum number of contingency landing sites.) Additionally, the requirement for a chase aircraft is simply an example of regulations lagging behind technology. Since the laws of the land (not the laws of physics) determine safety chase regulations, they can be changed as technology and risk dictate.[32]

Technology. Unmanned launch vehicles and unmanned spacecraft have dominated military space operations for nearly 40 years. Commercial airliners use GPS integrated navigation systems and automated flight controls to fly to their destinations and land safely. According to a recent article on cockpit automation published in *Design News,* "artificial intelligence and decision-aiding programming [will] turn the pilot's job into that of a flight supervisor," and even military fighter aircraft will "evolve into unmanned vehicles."[33] The growing USAF interest in unmanned air vehicles (UAV) such as Predator and Dark Star supports this prediction.



A robotic arm using its own vision-guided intelligence system, grabs a ball "floating" in microgravity aboard NASA's KC-135. The tests demonstrate that autonomous robots can use computer vision to guide robotic manipulation of objects.

Proponents of manned spaceplanes are more skeptical of artificial intelligence technologies. Their pragmatic outlook is summarized in this passage:

> In spite of rapidly increasing cockpit automation, it is expected that airliners will require pilots for the foreseeable future. Unpiloted airplanes to date have fallen short of safety standards required for a Certificate of Airworthiness. It therefore seems prudent to assume that an early spaceplane designed for flight safety will need to be piloted.[34]

Program Risk. Two arguments suggest unmanned systems will have the overall lower program risk. First, since it is generally believed that billions of dollars[35] will be needed to develop an MSP system already challenged with technological obstacles, adding upwards of 50 percent to the development costs to "man-rate" the vehicle[36] would make the program unexecutable in any conceivable budget environment. Second, assuming subscale technology demonstration vehicles are part of MSP development, they will almost certainly be unmanned since manned vehicles do not scale down easily. If this is the case, many technical issues (e.g., command and control) as well as legal issues (e.g., overflight of populated areas) would be solved out of necessity. Therefore, many criticisms of the unmanned approach could be worked out over the life of the program.[37]

However, proponents of manned vehicles point to empirical data that suggests technology demonstration vehicles must be of sufficient scale to accommodate an onboard pilot. Consider NASA's X-1 through X-29, which had a cumulative loss rate of only one vehicle per 140 sorties.[38] Compare this to various unmanned drones and cruise missile test programs, which exhibited loss rates from about one vehicle in 10 sorties to one vehicle in four sorties.[39]

An MSP Could Provide for Both Manned and Unmanned Operations. If a crew station can be inserted into the payload section, it may be possible to fly an MSP in either mode. "For crewed missions, a capsule is serviced off-line from the launcher . . . and then inserted into the next vehicle just like cargo."[40] Although the added design complexity of a bimodal configuration would certainly have its own costs and issues to be reckoned with, this proposal appears worthy of further consideration and study.

An MSP May Transition between Manned to Unmanned Operations during Development. There are four reasons why MSP flight operations might transition from manned for flight test to unmanned for operational missions. First, it is prudent to "expect the unexpected" during test flights, and this is precisely the environment where an onboard operator is the most beneficial. Second, obtaining government permission to let an unproven, unmanned million-pound vehicle fly over populated areas may be difficult.[41] Third, the manned test flights could collect the hypersonic aerodynamic data required by fully autonomous flight control systems without relying on these same control systems to collect the data. (Such data is difficult to model and predict using only computers and wind tunnels.) Finally, after the vehicle's reliability has been proven during flight test, most operational missions could be flown unmanned to maximize payload capability.[42] A number of current space-plane concepts, including Sanger, Delta Clipper, and Blackhorse, have proposed this strategy.

Interestingly, the Skylon space-plane design team proposed the exact opposite strategy. They suggest early prototypes should be unmanned to make the program affordable. Only when the vehicle technology matures should manned operation be attempted.[43]

Manned Systems May Be Less Vulnerable to Hostile Attack. The presence of a human on board a military space platform may add to its self-protection capability.

> The presence of humans provides a deterrent. A satellite in orbit, no matter how expensive, is just a piece of machinery. Nations don't go to war over machines. But put one seemingly insignificant soldier, sailor, or airman on that machine, and suddenly national sovereignty is threatened.[44]

Above: *The Mars Surveyor 2001 Lander is scheduled to land in early 2002. Hazardous or long-duration missions have always favored unmanned solutions, but air and space crews are not yet in any danger of extinction.* Below: *The Global Hawk UAV flies over Edwards Air Force Base, California, during its first flight.*

Man in Space Has Historical Precedence. The primary objective of NASA's manned space-flight programs from Project Mercury through the space shuttle was to put man in space, so unmanned alternatives were never even considered. Since the MSP will satisfy war-fighting requirements, comparing it to manned NASA programs is inappropriate.

Ironically, most of the literature surveyed for this study made almost no mention of one of the most important considerations of all—performance.[45] This suggests a significant gap in the current debate and helps illustrate one of its major shortcomings. Therefore, it is time to proceed beyond the simple manned-versus-unmanned paradigm to explore other possibilities.

The Man-Machine Interface Spectrum

> *There is no such thing as an unmanned system: everything that is created by the system designer involves man in one context or another.*
>
> —Stephen B. Hall

Man-machine interface designs are not limited to the two extremes of 100 percent manual and 100 percent automatic. Using NASA's 1984 study of the human role in space (THURIS) as a guide, this section identifies seven possible MMI modes for space system operation, presents a generic MMI selection algorithm, and makes a preliminary assessment of whether an MSP can benefit from on-board human participation given the mission requirements previously outlined.

The Human Role in Space Study

The THURIS study was designed to (1) investigate the role of humans in future space missions, (2) establish criteria for allocating tasks between men and their machines, and (3) provide insight into the technology requirements, economics, and benefits of humans in space.[46] By identifying common space-vehicle tasks, baselining human performance capabilities, and accounting for cost and technology factors, the researchers provided both a logical framework to attack the MSP man-machine interface problem as well as specific findings that provide insight to man's utility on board an MSP flight vehicle.

Defining the MMI Spectrum. The THURIS study identified seven MMI modes, spanning a "spectrum" from direct manual control to completely autonomous operation. Table 1 lists these modes and provides an example of each. Since most complex systems perform a variety of functions, it is not surprising that some employ multiple MMI modes. For example, the space shuttle ascends to orbit using an autopilot monitored by the astronauts (supervised, on board). Once it is in orbit, it uses the Remote Manipulator Arm (teleoperated) to deploy satellites that are later retrieved by pressure-suited astronauts attached to manned-maneuvering units (supported). During the final approach and landing phase, the pilot "flies" the shuttle not unlike a glider (manual), but has a number of sensors and instruments to assist him (augmented).

A Generic MMI Selection Process. To select from these seven possible MMI modes, the THURIS study identified the algorithm shown in figure 1. This conceptually straightforward algorithm considers performance, cost, schedule, and technology risk to arrive at a baseline MMI design. Four observations concerning figure 1 are worth mentioning.

First, performance consideration is an integral part of the process. In the manned-versus-unmanned debate, performance considerations were notably absent. Second, since the four space operations mission areas may require different functional tasks, it is conceivable that different missions will be best suited to different MMI modes. Third, although conceptually simple, an MMI selection process will require a great deal of effort to execute fully. Engineering trade studies, modeling and simulation efforts, and detailed cost estimates will all be needed. Finally, it is important to recognize the output of this selection process is one of the seven predefined MMI modes shown in table 1. Whether or not man ends up on board the flight vehicle is a by-product of this selection. This is in contrast to the conventional approach where the vehicle is either manned or unmanned as an a priori requirement.

Generic Space Tasks Identified in THURIS. By analyzing six space systems (ranging from manned space stations to unmanned satellites), the THURIS study concluded "the

Table 1

The Spectrum of Man/Machine Interface (MMI) Options

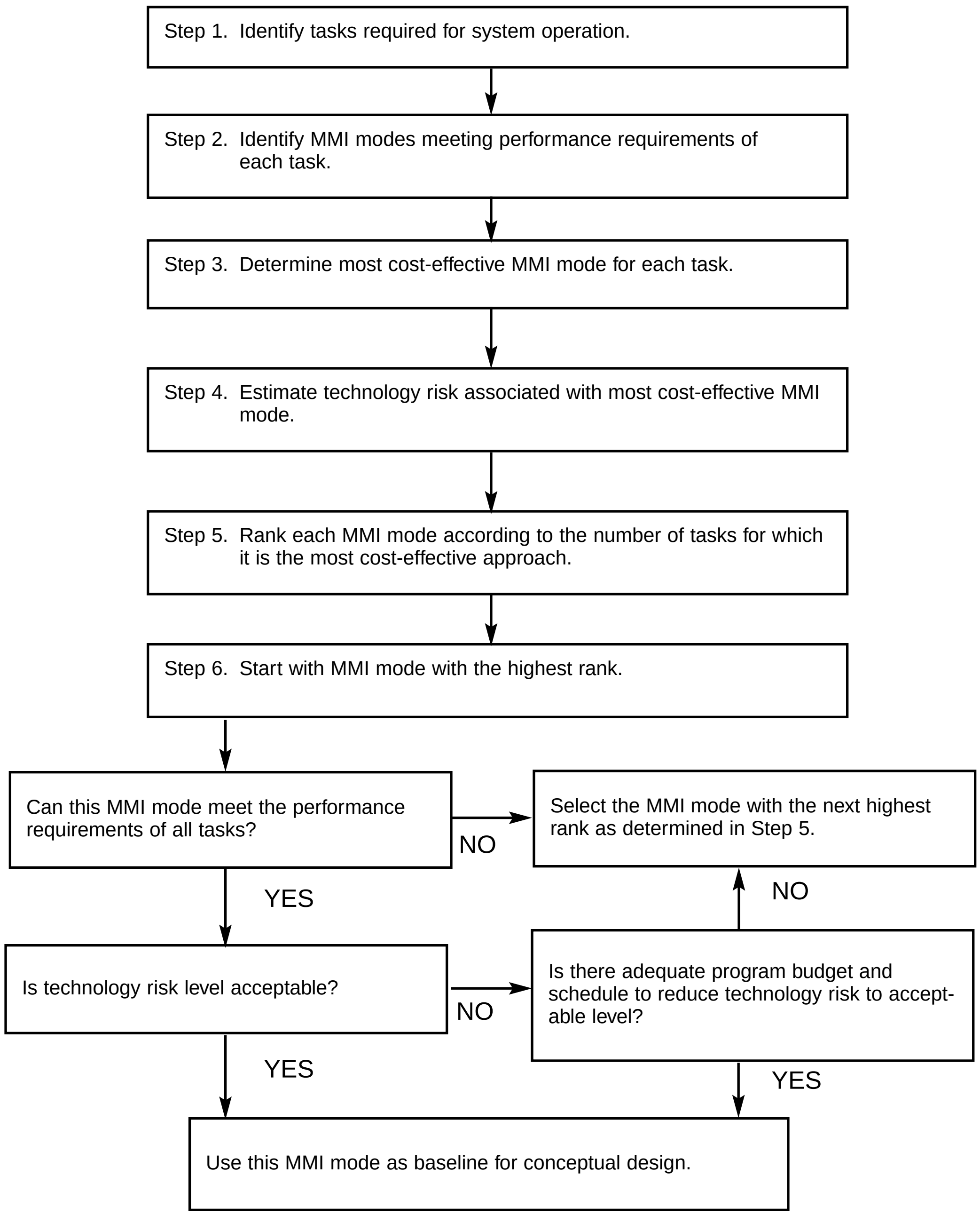
MMI Mode	Description	Example(s)
Manual	Unaided human operation	"Seat of the pants" piloting
Supported	Requires supporting machinery or facilities	Pressure suits; manned maneuvering units
Augmented	Amplification of human sensory or motor capabilities	Electro-optic sensors (amplify sensory capabilities); power tools (amplify motor capabilities)
Teleoperated	Use of remotely controlled sensors and actuators allowing humans to be removed from work site	Remote manipulator systems
Supervised (on board)	Replacement of direct, human control of system operation with computer control under human supervision. Human supervisor on board vehicle	Shuttle guidance, navigation, and control (GNC) system (monitored by astronaut)
Supervised (from ground)	Same as above, but human supervisor is on ground	Expendable launch vehicle GNC system (monitored by ground controller)
Independent	Self-actuating, self-healing, independent operations with minimal human intervention. (Requires automation and artificial intelligence)	Deep space probes

Source: Adapted from Stephen B. Hall, ed., *The Human Role in Space: Technology, Economics, and Optimization* (Park Ridge, N.J.: Noyes Publications, 1985), 2.

same basic activities were found to be required in different operations and in different missions."[47] Specifically, 37 "generic space tasks" were identified and assessed to determine the degree to which man's onboard participation contributed to the successful completion of each task.[48] The result, shown in table 2, orders these 37 tasks from those that most benefit from a human on board, to those that least benefit from a human on board.

MMI Selection for a Military Space Plane: A Preliminary Analysis. Consider figure 1 as a function that maps a task (input) to a specific MMI mode (output). Viewed together, tables 1 and 2 estimate this very same function when you realize that they "correlate" (in a conceptual sense) with one another from top to bottom! In other words, tasks listed near the top of table 2 (where man's onboard participation is "essential") will map into MMI modes near the top of table 1. Conversely, tasks near the bottom of table 2 (where man's onboard participation is "not significant") will map into MMI modes near the bottom of table 1.

More fundamentally, table 2 alone provides insight to whether or not an MSP stands to benefit from having a man on board at all—as long as "generic" tasks can be extrapolated from the previously described MSP mission requirements. Since some tasks (such as mission planning, launch, midcourse flight, and vehicle recovery) will be common to all MSP mission



Source: Stephen B. Hall, ed., *The Human Role in Space: Technology, Economics, and Optimization* (Park Ridge, N.J.: Noyes Publications, 1985), 21.

Figure 1. A Generic MMI Task-Allocation Process

Table 2

Benefit of Man's Participation in Space Activities

No.	Generic Space Task	Overall Benefit from Man's Onboard Participation	Comments
1	Problem Solving/ Decision Making	Essential	Man essential by definition
2	Implement Procedure/ Schedule	Essential	Activity dependent on man's participation by definition
3	Define Procedure, Schedule, Operation	Essential	Wholly dependent on man's intellectual activities
4	Apply/Remove Biomedical Sensors	Essential	Cannot easily be automated
5	Handle/Inspect Living Organisms	Essential	Activity cannot be automated in most cases.
6	Surgical Manipulations	Essential	Activity not appropriate for automation
7	Precision Manipulation	Most often Essential	Man's manipulative skills cannot be duplicated by automatic devices.
8	Connect/Disconnect Electrical Interfaces	Beneficial to Essential	Typical utilization of man's basic capabilities
9	Connect/Disconnect Fluid Interfaces	Beneficial to Essential	Typical utilization of man's basic capabilities
10	Gather/Replace Tools & Equipment	Beneficial to Essential	Man can vary tool selection with respect to task.
11	Release/Secure Mechanical Interface	Beneficial to Essential	Exemplary utilization of man's capabilities in space activities
12	Replace/Clean Surface Coatings	Beneficial to Essential	Infrequency of activity negates automation.
13	Replenish Materials	Beneficial to Essential	Degree of benefit is dependent on nature of task.
14	Display Data	Beneficial to Essential	Man important in selection of data to be displayed
15	Information Processing	Beneficial to Essential	Essential interaction between man and computer
16	Detect Change in State or Condition	Beneficial to Essential	Strongly dependent on characteristics of activity
17	Inspect/Observe	Highly Beneficial	Man's selective observations superior to automated monitoring
18	Adjust/Align Elements	Beneficial	Most alignment operations within man's capabilities

Table 2––Continued

No.	Generic Space Task	Overall Benefit from Man's Onboard Participation	Comments
19	Deploy/Retract	Beneficial	Seldom repeated activities are poor candidates for automation.
20	Measure (scale) Physical Dimensions	Beneficial in Some Cases	Man is best alternative in some situations.
21	Position Module	Beneficial in Some Activities	Man's benefit highly dependent on type of activity
22	Remove Module	Beneficial for Some Activities	Man's benefit highly dependent on type of activity
23	Remove/Replace Covering	Beneficial for Some Activities	Man's benefit highly dependent on type of activity
24	Pursuit Tracking	Could be Significant	Dependent on specific tracking task
25	Transport (loaded)	Dependent on Specific Task	Characteristics of tasks can vary extensively for this activity.
26	Transport (unloaded)	Dependent on Specific Task	Characteristics of tasks can vary extensively for this activity.
27	Activate/Initiate System Operation	Not Significant	Automatically activated systems will predominate.
28	Allocate/Assign/Distribute	Not Significant	Primarily automated operations
29	Communicate Information	Not Significant	Communication links established automatically
30	Compensatory Tracking	Not Significant	Highly dependent on nature of tracking task. Nullifying error signal can be automated.
31	Compute Data	Not Significant	Man's role in data computation is negligible.
32	Confirm/Verify Procedures, Operations	Not Significant	Man would usually function in a "back-up" role.
33	Correlate Data	Not Significant	Man would usually function in a "back-up" role.
34	Deactivate/Terminate System Operation	Not Significant	Automatically deactivated systems will be the norm.
35	Decode/Encode Data	Not Significant	Basic computer function
36	Plot Data	Not Significant	Primarily a computer function
37	Store/Record Element	Not Significant	Man's participation of benefit only in isolated cases

Source: Adapted from Stephen B. Hall, ed., *The Human Role in Space: Technology, Economics, and Optimization* (Park Ridge, N.J.: Noyes Publications, 1985), 8–9.

areas, let's begin by categorizing these in terms of the "generic" tasks shown in table 2.

Mission Planning involves defining procedures, schedules, and operations (task 3) and making decisions about targets, trajectories, and other mission-specific variables (task 1). When a military commander decides to launch an MSP sortie (task 1), he or she will issue an order to implement predefined procedures, schedules, and operations (task 2). As shown in table 2, man's participation in all these tasks is "essential," but they are all performed before the MSP ever leaves the ground.

Man's role changes significantly after launch. The predominant MSP task throughout launch, midcourse trajectory execution, and recovery is staying on a preplanned trajectory.[49] This explicit guidance function is fundamentally a compensatory tracking task (task 30). Throughout the mission, subsystems and payloads will be activated and deactivated (tasks 27, 34), sensor data will be processed and computationally manipulated (task 31), commands will be uplinked and mission data will be downlinked (task 29), and sensor data will be recorded for postflight analysis (task 37). According to table 2, man's onboard role in all these tasks is "not significant." UAVs, expendable launch vehicles, and on-orbit satellites are all consistent with this assessment.

But what happens if the MSP encounters an unplanned event such as a subsystem failure, hostile attack, or forced change in landing site? Deciding on an appropriate course of action (task 1) will most certainly require human intervention—although from where is not yet clear. The probability of an unplanned event occurring, its impact on the mission, and man's ability to affect the outcome depend on a wide range of factors. These include the specific MMI mode implemented, the reliability and maturity of the MSP system, and the fidelity of its environmental and threat models. These issues are beyond the scope of this preliminary assessment and can only be resolved by a more detailed analysis, such as outlined in figure 1.

Other MSP tasks will be peculiar to individual mission types. For example, if kinetic energy munitions are used, application of force and space control missions will require weapons released from a mechanical interface (task 11). Although table 2 defines man's involvement in this task as "beneficial to essential," many examples exist to suggest this assessment is not applicable to all cases. Reentry vehicle release from the upper stage of an intercontinental ballistic missile (ICBM) is a case in point. And even in the F-16, where a human pilot is present, the actual weapons release task might be categorized as teleoperated[50] or supervised,[51] but certainly not manual (see table 1).

No hardware need be deployed in such enhancing operations missions as photoreconnaissance and communications support. While precision alignment of optics, sensors, and antennae might be required (task 13), man's participation may not necessarily be "beneficial" as shown in table 2. Even now, there are scores of unmanned remote-sensing and communications satellites with very precise pointing and attitude control requirements that do not require a man on board for successful operation.

Supporting space-forces missions is a different story, however. Looking beyond the simplest case of space lift to more aggressive missions involving repair, refueling, and retrieval of on-orbit satellites, many challenging tasks are envisioned. Repair missions will require inspection of damaged components (task 17) and precision handling of tools and equipment (tasks 7, 10). On-orbit refueling will require connection/disconnection of fluid interfaces (task 9) and materials replenishment (task 13). Satellite retrieval will require positioning objects precisely enough to secure a mechanical interface (task 11). In each of these tasks, man's onboard presence is either essential or beneficial. Therefore, complex supporting-space forces missions will definitely benefit from, and may in fact require, onboard human operators.

One final comment on space control is in order. As has already been discussed, destructive space-control missions that deploy hard-kill projectiles may benefit little from onboard human operators. However, disruptive space-control operations are different. These missions may require close inspection (task 17), precision manipulation (task 7), and physical disruption (tasks 8, 9, 11). Resembling supporting space forces more than application of force, disruptive space-control missions may also require on-the-scene human intervention.

In summary, this intuitive (but preliminary) MSP task analysis has led to some interesting insights. It suggests an onboard human operator may be required for most supporting space forces and some disruptive space control missions. On application of force, enhancing operations, and destructive space-control missions, however, the value added by a man on board is far less certain. The implications of these findings on MSP operating concepts and program-development strategies will be explored further in the final section.

Conclusions and Recommendations

A military space plane could play a key role in helping the United States Air Force transform itself from an air force into an aerospace force. Many long-range studies have concluded a reusable, hypersonic vehicle operating in both the air and space media should be developed to ensure our space dominance in the twenty-first century. The purpose of this essay has been to investigate just one part of MSP development—the concept for man's participation in MSP flight operations.

The Old Paradigm: Manned versus Unmanned

The current literature focuses primarily on only two man-machine interfaces: manned and unmanned. The manned argument centers on the fact that humans provide flexibility to deal with unknown and unplanned situations. The more quantitative unmanned argument focuses on the decreased cost of not having to man-rate the vehicle and the performance advantages of not having to lift the mass of the crew and their life-support systems to orbit. Other factors such as technology readiness, program-development risk, and flight safety are not so clearly resolved. The expert opinions, supporting data, and logical development presented by each side are equally compelling. Considering the body of literature surveyed, this debate is stuck at an impasse.

A New Approach: The Spectrum of MMI Options

What each side fails to acknowledge, however, is that man-machine integration is not limited to only two design options. We must progress beyond the old paradigm of manned versus unmanned and focus instead on the degree of man's involvement in space-plane operations. There are many possible man-machine interface options, and man has a key role to play in each of them. Whether piloting an MSP from its cockpit, monitoring mission operations from its cargo bay, remotely controlling its flight from a ground operations center, or simply pushing a button to initiate an otherwise autonomous mission, man *will* be a part of space-plane flight operations.

Determining which of these roles man will play requires a detailed engineering analysis integral to the baseline design of an MSP system. Mission requirements must be broken down to their most elementary level tasks. For each task, MMI modes capable of meeting the stated performance requirements should be ranked according to cost. A structured analysis can then be completed to determine the optimal MMI solution for the system as a whole—based on performance, technology, cost, risk, and schedule considerations. A conceptually straightforward selection process was presented, but the messy details of working through this process remain to be accomplished.

One very important aspect of this MMI selection process needs to be emphasized. Simply stated, the optimum man-machine interface type is a design solution of, not a requirement for, the MSP vehicle. Therefore, MSP mission-need statements and system requirements documents should avoid specifying any particular MMI implementation. Instead, detailed mission performance requirements should be identified and prioritized. As currently envisioned, the MSP will be a "multirole" platform, satisfying all four space mission areas. Since different tasks are needed to satisfy each of these mission areas, the optimum MMI modes for each could also be different.

Cockpit, Cargo Bay, or Ground Control?

This study has suggested that application of force, enhancing operations, and destructive space-control missions will benefit little from man's "hands-on" participation. This assessment is supported empirically by a variety of existing aerospace systems, to include expendable launch vehicles, unmanned satellites, and ICBMs. On the other hand, aggressive supporting space forces missions, such as repairing and refueling on-orbit satellites and "disruptive" space-control missions, could benefit greatly from man's on-site participation. These missions rely more on the precision handling, close inspection, problem solving, and ingenuity that only man can provide.

These results suggest an MSP that can be implemented in two phases. A first-generation MSP could function without a man on board—but whether it operates autonomously or under the close supervision of ground controllers remains to be seen. This first-generation MSP could execute at least a portion of all four space-mission areas. It could overfly any point on the planet to deliver a strike payload or conduct a reconnaissance mission. On a counterspace mission, it could destroy hostile satellites using kinetic-energy projectiles or directed-energy beams. As a reusable launch vehicle, it could perform a simple yet critical space support mission—satellite deployment.

Many factors support the development of a first-generation MSP without men on board. First, it could satisfy the near-term mission requirements—surveillance/reconnaissance and defensive counterspace—as well as perform at least a limited role in all four space-mission areas. As the less expensive alternative, it stands a greater chance of being funded. Finally, the absence of a crew, their life-support equipment, and a dedicated cockpit help reduce the vehicle's operating weight. Given the technical challenges involved with single-stage-to-orbit flight, any opportunity to reduce the vehicle's mass is advantageous.

But how will the more complex space-control and supporting space-forces missions be performed if they require direct manned intervention? The answer may reside in a second-generation MSP upgrade: an optional "crew support module" installed in the payload bay. This module could carry humans to orbit where they would operate outside the confines of the MSP using space suits and manned maneuvering units. This would afford their uniquely human talents such as problem solving, close inspection, and precision handling the maximum freedom of maneuver to accomplish these more demanding missions.

Inserting a crew-support module into the payload bay would eliminate the need to develop a totally unique MSP for crewed operations. Integration of the module to the baseline MSP would be simplified because the mission focus of the men on board will be external to the vehicle—either on the friendly satellite to be serviced or the hostile satellite to be disrupted. In fact, any effort to turn the crew-support module into a "cockpit" could significantly increase the cost and complexity of the module itself (since additional controls and displays would have to be added) and the baseline MSP (since multiple control and feedback paths would have to be incorporated). Although having the capability to manually "fly" the MSP using onboard controls sounds appealing, the costs and benefits of doing so need to be considered carefully.

In closing, this study has proposed a new perspective from which to approach the manned-versus-unmanned space-plane problem. Even though the applicability of its specific findings should be tempered by the preliminary nature of the MMI analysis conducted, some interesting insight has been achieved. Clearly, man will play an active role in MSP flight operations, and there could never be a truly unmanned space plane. But for most missions, the appropriate place for humans appears to be on the ground in the control room. Stated more generally, these findings suggest man-in-the-loop does not necessarily require man on board.

On those missions that do require human intervention in orbit, man might be most valuable operating out of a crew-support module installed in the cargo bay, with his attention focused more primarily on the external environment. Extrapolating this finding to more general terms suggests a highly provocative question: Are manned vehicles necessarily piloted vehicles? Our ability to satisfactorily answer this question will depend on our technology. But our willingness to just explore the possibility will depend more on our organizational culture. □

Notes

1. *SPACECAST 2020* is an Air University study published in 1994 that identified high-leverage space technologies and systems that would best support the war fighter and could be fielded by the year 2020. An on-line version can be found at www.au.af.mil/Spacecast/Spacecast.html.

2. Air University, *SPACECAST 2020*, vol. 1, *Operational Analysis* (Maxwell AFB, Ala.: Air University, 1994), appendix 8, 65.

3. *New World Vistas*, a USAF Scientific Advisory Board study to search for advanced air and space ideas, was published on 15 December 1995—the 50th anniversary of the first USAF Scientific Advisory Report: *Toward New Horizons*. The *New World Vistas* summary volume is at http://web.fie.com/htdoc/fed/afr/sab/any/text/any/vistas.htm.

4. Air Force Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century*, attack volume (Washington, D.C.: USAF Scientific Advisory Board, 1995), ix.

5. *Air Force 2025* identifies concepts, capabilities, and techniques needed for the United States to remain a dominant air and space power in the twenty-first century. See *Air Force 2025* (Maxwell AFB, Ala.: Air University Press, 1996), n.p.; on-line, Internet, 23 September 1996, http://www.au.af.mil/au/2025.

6. Ibid.

7. Air Force Doctrine Document (AFDD) 2-2, *Space Operations*, 23 August 1998.

8. Ibid., 8–10.

9. Ibid., 11.

10. Ibid.

11. Ibid., 12.

12. AFSPC MNS 001-97, "Tactical Military Operations in Space," draft (version 5.9), November 1997, 4.

13. Ibid., 3.

14. Ibid.

15. Ibid., 1.

16. Maj Ken Verderame and Maj Andrew Dobrot, "System Requirements for a Military Spaceplane," draft (version 1.0), MSP Program Office, Air Force Research Laboratory, Kirtland AFB, N.M., April 1997.

17. Ibid., 9.

18. Ibid., 21.

19. Ibid.

20. Lt Col Joseph A Carretto, USAF, "Military Man in Space—Essential to National Strategy," Research report no. NDU-ICAF-95-S3 (Washington, D.C.: Industrial College of the Armed Forces, 1995).

21. The cited reference defines *serendipity* as "the capability of making unexpected discoveries by accident."

22. Air Force Space Command study, "The Utility of Military Crews in Space" (draft), 1985, in Theodore Wierzbanowski, *Manned vs. Unmanned: The Implications to NASP*, AIAA-90-5265 (Orlando, Fla.: AIAA Second International Aerospace Planes Conference, 1990), 10.

23. Russell J. Hannigan, *Spaceflight in the Era of Aerospace Planes* (Malabar, Fla.: Krieger Publishing Co., 1994), 229.

24. Richard Varvill and Alan Bond, "Skylon: A Key Element of a Future Space Transportation System," *Spaceflight* 35, no. 5 (May 1993): 164.

25. Mark Gottschalk, "Computers Take over the Cockpit," *Design News* 51 (4 November 1996): 98.

26. Hannigan, 108.

27. Ibid., 132.

28. *SPACECAST 2020*, vol. 1, section H, appendix C, H 40–41.

29. Wierzbanowski, 9.

30. Ibid., 7.

31. The space maneuver vehicle, an experimental vehicle built for a military space-plane technology program office by Boeing/North American, has an autonomous landing capability using differential GPS. This capability was successfully demonstrated in August 1998.

32. The flight-test program for the X-33, an unmanned reusable launch vehicle being developed by NASA and Lockheed Martin, calls for suborbital flights between Edwards AFB, California; Michaels AAF, Utah; and Malmstrom AFB, Montana. In addition to developing and maturing space-plane vehicle technologies, the X-33 program may also dictate a modification of federal aviation regulations.

33. Gottschalk, 90, 94.

34. David Ashford, "The Potential of Spaceplanes," *The Journal of Practical Applications in Space* 6, no. 3 (Spring 1995): 224.

35. A 1994 OUSD/A&T report, "Space Launch Modernization Plan," estimated space-plane development costs between $6–20 billion. According to Maj Ken Verderame at the MSP Program Office, recent estimates are closer to $2 billion for one suborbital concept-demonstration vehicle and one orbit-capable space plane.

36. Varvill and Bond, 164.

37. The X-33 may be a case in point (see endnote 32).

38. Jay Miller, "The X-Planes, X-1 to X-29," in Wierzbanowski, 10.

39. Wierzbanowski, 9.

40. Hannigan, 108.

41. Again, the NASA X-33 may break new ground in this area that would benefit future military space-plane flight testing (see endnote 32).

42. Ibid., 228.

43. Varvill and Bond, 164.

44. Carretto, 27.

45. Performance was usually addressed only in terms of throw weight (or payload fraction) for space-lift missions.

46. Stephen B. Hall, ed., *The Human Role in Space: Technology, Economics, and Optimization* (Park Ridge, N.J.: Noyes Publications, 1985), v.

47. Ibid., 4.

48. Ibid., 22 (fig. 18).

49. All current space launches follow preplanned trajectories into predefined orbits. Even aircraft air-to-ground strike missions are planned using defined ingress routes, target-attack headings, and egress routes. Therefore, both space launches and aircraft missions have "trajectories" that are defined in terms of time and space.

50. An example is the CCIP (continuously computed impact point) delivery mode.

51. An example is the CCRP (continuously computed release point) delivery mode.